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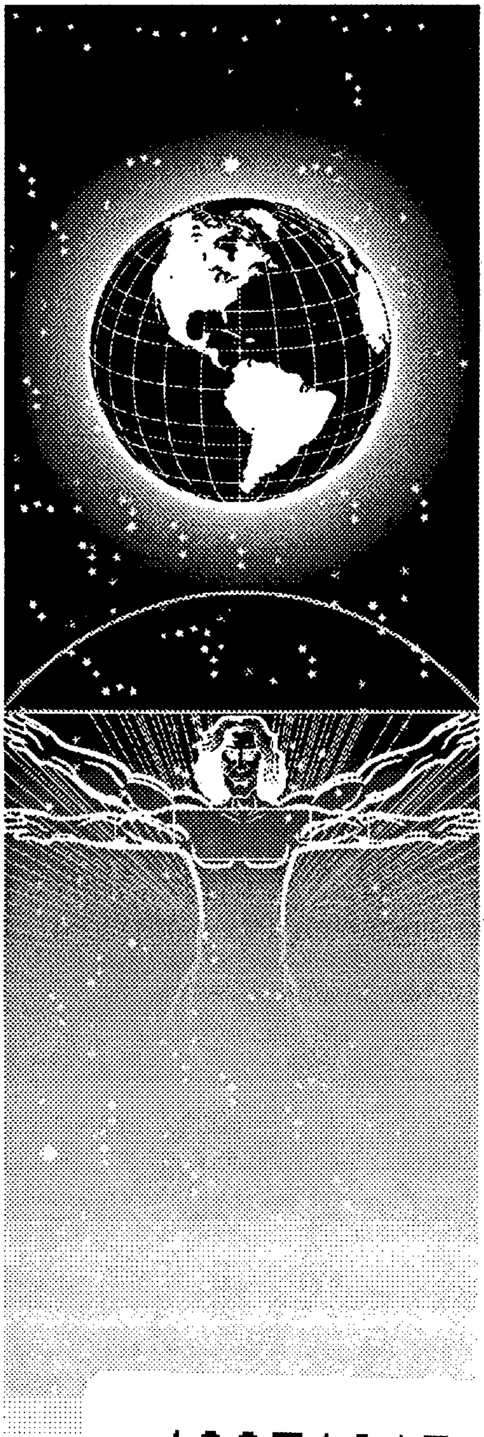

UNITED STATES AIR FORCE
ARMSTRONG LABORATORY

The Effect of Multiple High +Gz Exposure on Male and Female Isometric Strength in Both Rested and Sleepless Conditions

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The voluntary informed consent of the subjects in this research was obtained as required by Air Force Instruction 40-402.

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE DIRECTOR

Thomas J. Moore

THOMAS J. MOORE, Chief
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BACKGROUND: The inclusion of women into the high performance aircraft community has raised several questions concerning body strength as it relates to cockpit performance and muscular fatigue. This study evaluated isometric strength of men and women pre- and post-G exposure in both a rested and sleepless state. METHODS: Fourteen subjects (8 male and 6 female) took part in a study which evaluated isometric strength pre-and post-Gz acceleration using a static ergometer which emulated aircraft controls. Isometric strength measures were obtained pre-and post-G acceleration in both rested (8 hours of rest) or sleepless (24 hours no sleep) conditions. G-exposure consisted of flying four (3 minute) closed loop flight simulations in the Dynamic Environment Simulator (centrifuge). RESULTS: No significant changes in strength were observed within groups of men and women when comparing pre-G rested upper and lower body strength measures. There were, however, significant differences between both groups. Women were 53 percent as strong as the men. CONCLUSIONS: Despite the significant differences in baseline strength measures between men and women, there were no significant differences in maximum isometric strength post-G acceleration in either the rested or sleepless conditions.

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PREFACE

This work was completed under PROJECT/TASK/WORKUNIT 71844501. The research was conducted in the Combined Stress Branch (AL/CFBS), Biodynamics and Biocommunications Division, Crew Systems Directorate, Armstrong Laboratory, Wright-Patterson AFB, OH.

The authors wish to express their appreciation to Dr. Joseph McDaniel of the Human Engineering Division (AL/CFHD) for his assistance and guidance at the various stages of this program, to the Dynamic Environment Simulator operations crew for their patience and "can do" attitude, and to the DES subjects who gave a 100% effort even after having been awake for 24 hrs.

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INTRODUCTION

The introduction of women into the high performance fighter aircraft arena has raised many issues concerning pilot strength and stamina and their relationship to maintaining consciousness during high-G air-to-air combat. There is no disputing the fact that women on average are about 50 percent as strong as men in upper body strength (1). In 1973, the Federal Aviation Administration (FAA) took a proactive approach in addressing the aircraft control force standards set for civilian aircraft manufacturers in terms of gender-specific strength differences. Results from an independent study conducted for the FAA revealed that these standards were set too high to accommodate the majority of the women with commercial flight certification. This resulted in a revision of the FAA standards set for commercial aircraft manufacturers (2). The United States Air Force (USAF) has also established a proactive approach to establish standards for maximum force required to operate various aircraft controls for a variety of aircraft. One Air Force study, conducted by McDaniel et al., reported on static aircraft control isometric strength of both male and female Air Force Academy and Officers Training School cadets. In addition to the obvious strength differences between the two groups, he also showed that available strength differed with the direction of force (3).

It was previously speculated that the difference in strength between men and women would compromise a woman's ability to perform in a high-G environment, and that this difference in strength may lead to early muscle fatigue resulting in compromised physiology and performance during exposure to high-G and culminating in gravity-induced loss of consciousness (G-LOC). This opinion, however, is not supported by quantifiable physiologic data collected in the high-G environment or by post-acceleration isometric strength evaluations reported herein.

This study examined isometric strength capabilities of men and women both prior to and immediately following the completion of four high-G simulated air-to-air combat sorties in two conditions, well rested and after 24 hours of sleeplessness.

METHODS

Subjects were members of the Armstrong Laboratory Sustained Acceleration Panel, Wright-Patterson AFB, OH. All participants had been briefed and had given informed consent prior to their participation in this study. Fourteen subjects participated including 8 males and 6 females ranging in age from 21 to 41 (mean age 27 years). Subjects were dressed in a standard issue flight suit and boots for all tests. All subjects met the JPATS or F-22 occupant standards for height and weight (4).

Strength Test Equipment

The strength test equipment used in this study was a custom made semi-automatic static ergometer which measured isometric strength of subjects manipulating simulated aircraft controls. Figure 1 shows a subject sitting in the device in the standard test position used to measure upper-body strength.

The test device was comprised of two components, the examiner's control/display unit and the subject test station. The control/display unit sat upon a countertop positioned so that the test subject could not see the results of the test. The control unit allowed the operator to select the test condition and direction to be evaluated. The LED display provided a three-second average of isometric strength in pounds. The five-second test period started automatically when the subject applied force exceeding five pounds on a hand control and 25 pounds to the foot control assembly. None of the aircraft controls being tested moved, but isometric forces were measured via strain gauge force transducers of 4448 N (1000 pounds) capacity.

The hand control evaluated in this study was the yoke-type aileron/elevator control simulated by three hand grip positions located on top of a vertical column. The handle centers were 356 mm (14 inches) above the seat reference point which is typical for aircraft. The two outside handles which represented an aircraft control yoke were located 178 mm (7 inches) to the left and right of center. This assembly measured forces when subjects pushed forward and pulled backward on the yoke. The yoke also measured forces generated while turning the yoke clockwise and counterclockwise. Leg strength was measured using a foot pedal assembly which pivoted on a roller bearing about a vertical axis. This design limited testing to one leg at a time.

The seat had one inch of foam padding and was adjustable in the fore and aft directions. The seat back angle was 13 degrees aft of vertical and the seat pan was tilted upward five degrees. In addition, maximum isometric strength was measured during the operation of the aircraft seat ejection handles. These ejection handles were mounted on the right and left sides of the seat. The handles were specially designed to have the same size, shape motion envelope, and force displacement of the ACES II ejection seat handles. The handles had limited motion and required 116 in-lbs of break-out force to initiate the ejection sequence. A more detailed description of the ejection handle system can be found in McDaniel (3).

Test Procedure

Subjects entered the testing area and were seated and secured in the aircraft seat. The seat was adjusted so that the subject's knee angle was between 130 and 140 degrees. Subjects were briefed on the testing procedures prior to performing the task. Each test condition was repeated three separate times with a two-minute rest period between trials. The highest force value generated during the three trial series was used as the datum for a particular condition. Test conditions were randomized across subjects. Figure 1 shows a subject seated and secured in the test device in position for the upper-body strength evaluation. Strength tests were performed prior to entering the centrifuge and immediately following centrifugation.

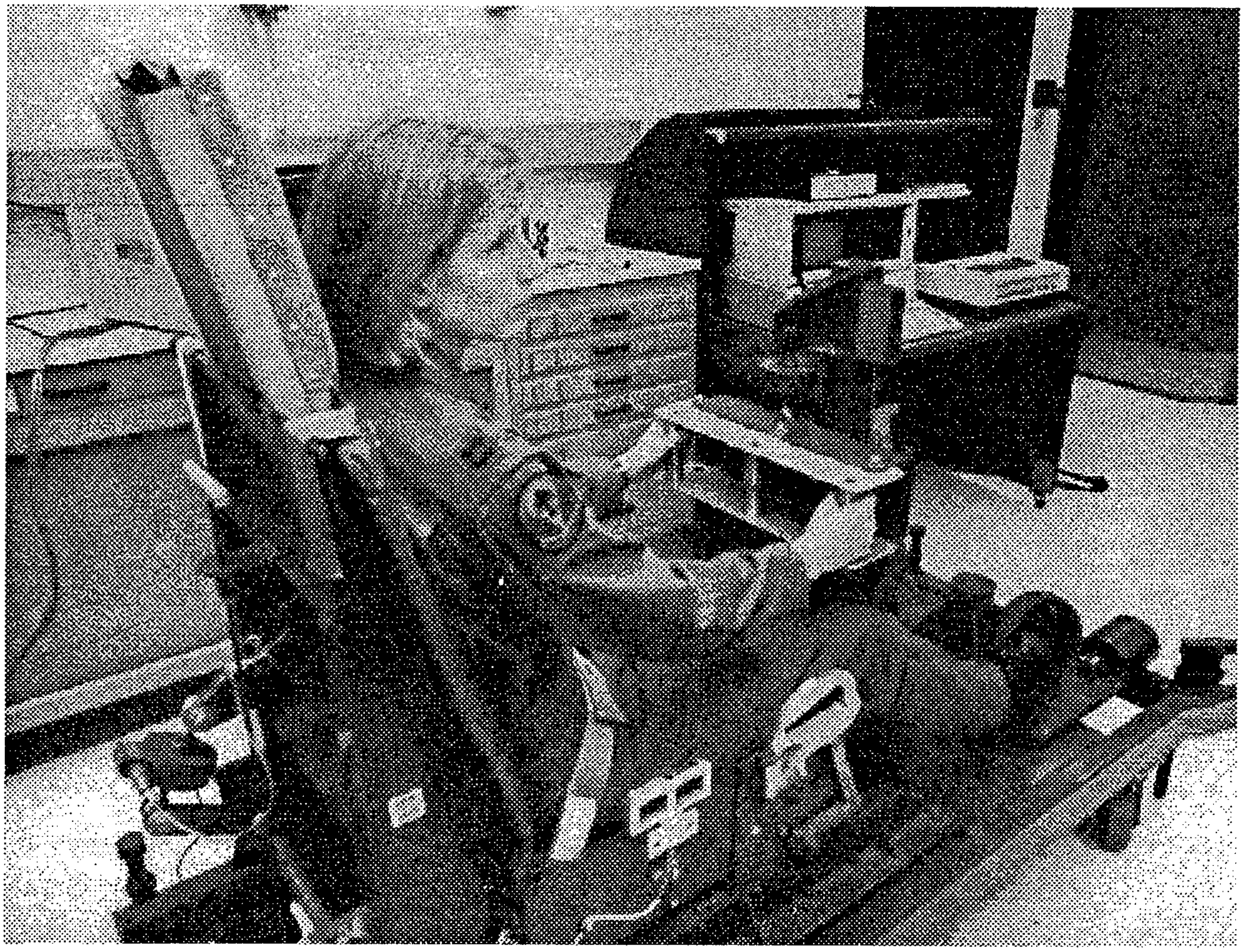

Figure 1. Subject Seated in the Static Ergometer in Position for an Upper-Body Strength Test.

Centrifuge

Following a pre-acceleration examination by the flight surgeon, the subject was ready for instrumentation. Prior to entering the centrifuge, subjects donned their G-protective equipment which included the standard CSU-13B/P anti-G suit and COMBAT EDGE positive pressure breathing for G helmet, mask, and counter pressure vest. Subjects were then seated in the gondola in an ACES II like seat (30 degree seat back angle) and "flew" two static 1 Gz simulated missions.

After having flown the two missions statically, the dynamic closed-loop missions began (Figure 2). Each sortie lasted three minutes with a three-minute rest between missions. Subjects were given full +9 Gz command authority of the centrifuge throughout the mission.

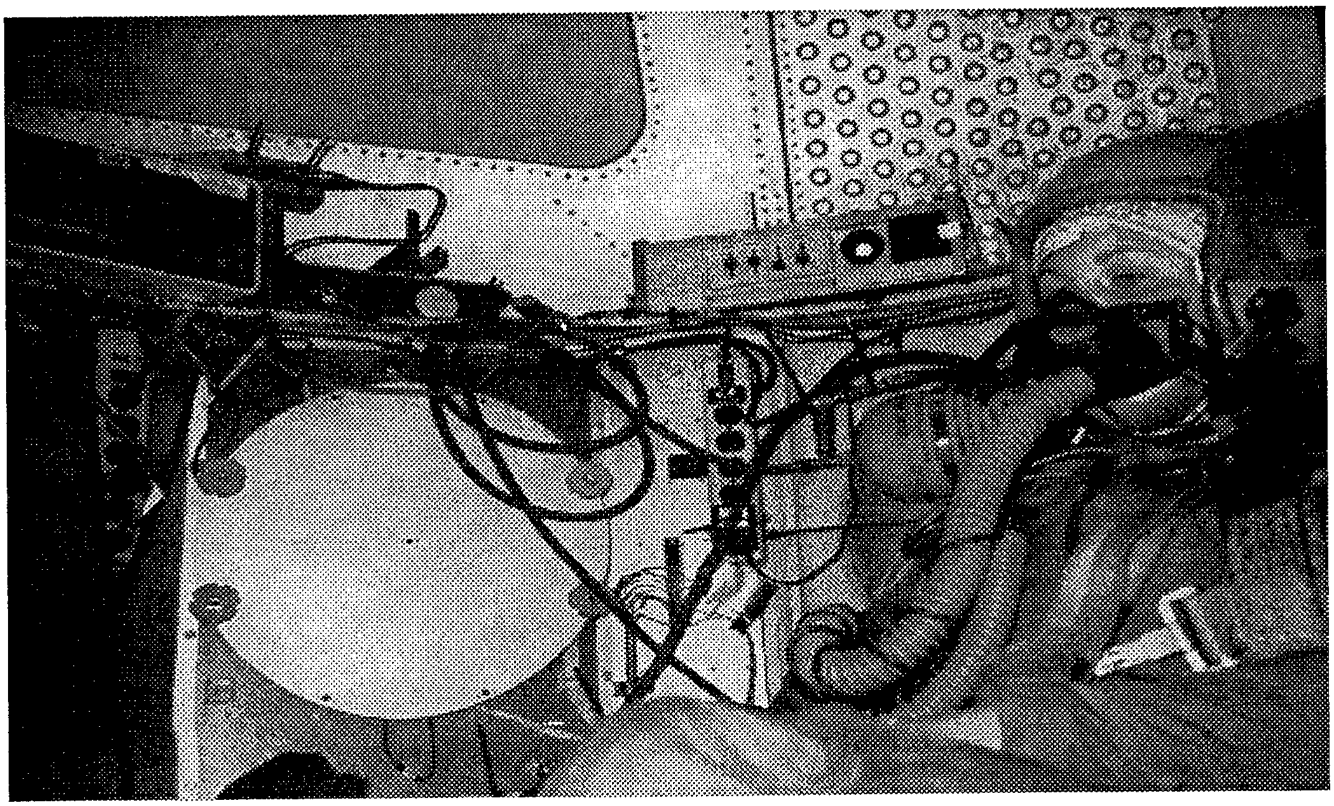

Figure 2. Subject Seated in the Gondola of the DES Prior to the +Gz Exposure.

A more detailed description of this performance task is published elsewhere (5). Once the subject had completed four sorties on the centrifuge, he/she returned to the static ergometer to complete the post-G series of upper- and lower-body strength measures.

This sequence of strength testing was standardized for both the rested and 24-hour sleep deprived conditions. Data were transcribed from the LED readout to a data sheet and later input into Microsoft Excel data files.

RESULTS

Data Analysis

Statistical analysis was accomplished using an ANOVA with a level of significance set at $p \leq 0.05$. A comparison of pre-acceleration yoke left, yoke right, yoke forward, and yoke backward force to post-G strength values revealed no statistically significant changes in strength in either the male or female group. The same findings were also observed when comparing pre-baseline sleepless data to post-G sleepless values.

Upper-body strength data for men and women for the rested pre-G and rested post-G conditions are shown in Table 1. A within group comparison of these data showed no significant change in post-G rested upper-body strength when compared to the pre-acceleration values. A between group comparison revealed a significant difference in pre and post isometric upper-body strength $p \leq 0.0001$ across rested conditions.

TABLE 1. Mean Upper Body Strength (Pounds) Pre- and Post-G: Rested.

	Yoke Left	Yoke Right	Yoke Forward	Yoke Backward
Men Pre-G	118 ± 22	126 ± 24	234 ± 52	211 ± 26
Men Post-G	104 ± 22	110 ± 17	248 ± 24	218 ± 32
Women Pre-G	54 ± 18	59 ± 21	105 ± 30	114 ± 27
Women Post-G	58 ± 15	65 ± 19	144 ± 40	128 ± 29

Table 2 shows these same data for the strength values collected during the sleepless phase of the experiment both pre- and post-G. Statistical analysis of these data revealed no significant changes in any of the upper-body strength conditions measured. A between group comparison revealed a significant difference in pre and post isometric upper-body strength $p \leq 0.0001$ across sleepless conditions.

TABLE 2. Mean Upper-Body Strength (Pounds) Pre- and Post-G: Sleepless.

	Yoke Left	Yoke Right	Yoke Forward	Yoke Backward
Men Pre-G	112 ± 17	111 ± 14	229 ± 47	224 ± 35
Men Post-G	107 ± 31	109 ± 24	230 ± 45	212 ± 52
Women Pre-G	61 ± 19	69 ± 20	127 ± 41	123 ± 30
Women Post-G	53 ± 21	59 ± 17	120 ± 38	114 ± 20

Tables 3 and 4 show the average lower-body force generated on the left and right rudder pedals. Again, these data are not significantly different within groups in the rested vs sleepless conditions. Significant differences were observed when comparing men to women.

TABLE 3. Mean Lower-Body Strength (Pounds) Pre- and Post-G: Rested.

	Left Leg	Right Leg
Men Pre-G	572 ± 133	555 ± 145
Men Post-G	573.7 ± 162	567.8 ± 213
Women Pre-G	280 ± 139	298 ± 129
Women Post-G	328.8 ± 101	303.6 ± 118

TABLE 4. Mean Lower-Body Strength (Pounds) Pre- and Post-G: Sleepless.

	Left Leg	Right Leg
Men Pre-G	581 ± 187	609 ± 173
Men Post-G	587 ± 239	558.3 ± 243
Women Pre-G	317 ± 126	328 ± 128
Women Post-G	367 ± 153	370 ± 135

Figures 3 and 4 illustrate male and female post-G sleepless upper- and lower-body strength data which were not statistically different from rested pre-acceleration values.

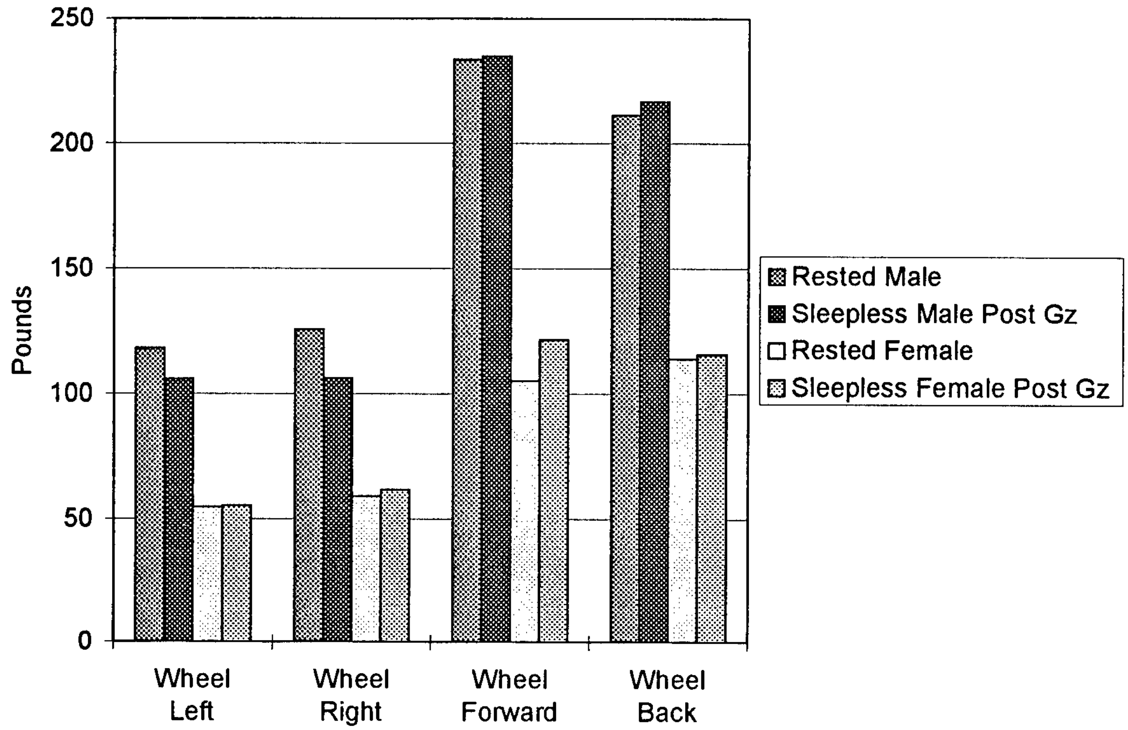

Figure 3. Mean Upper-Body Strength of Men and Women in the Rested Pre-Baseline and Post-G Sleepless Conditions.

One interesting piece of subjective data from this study was the response of test subjects when asked if they had performed better or worse on the strength test after having been up for 24 hours and after having been exposed to high-G. Twelve of the fourteen subjects responded that they had performed worse in the post-G sleepless condition. Quantitative strength data showed that subjects performed about the same or better in the post-G sleepless condition compared to the pre-G rested data.

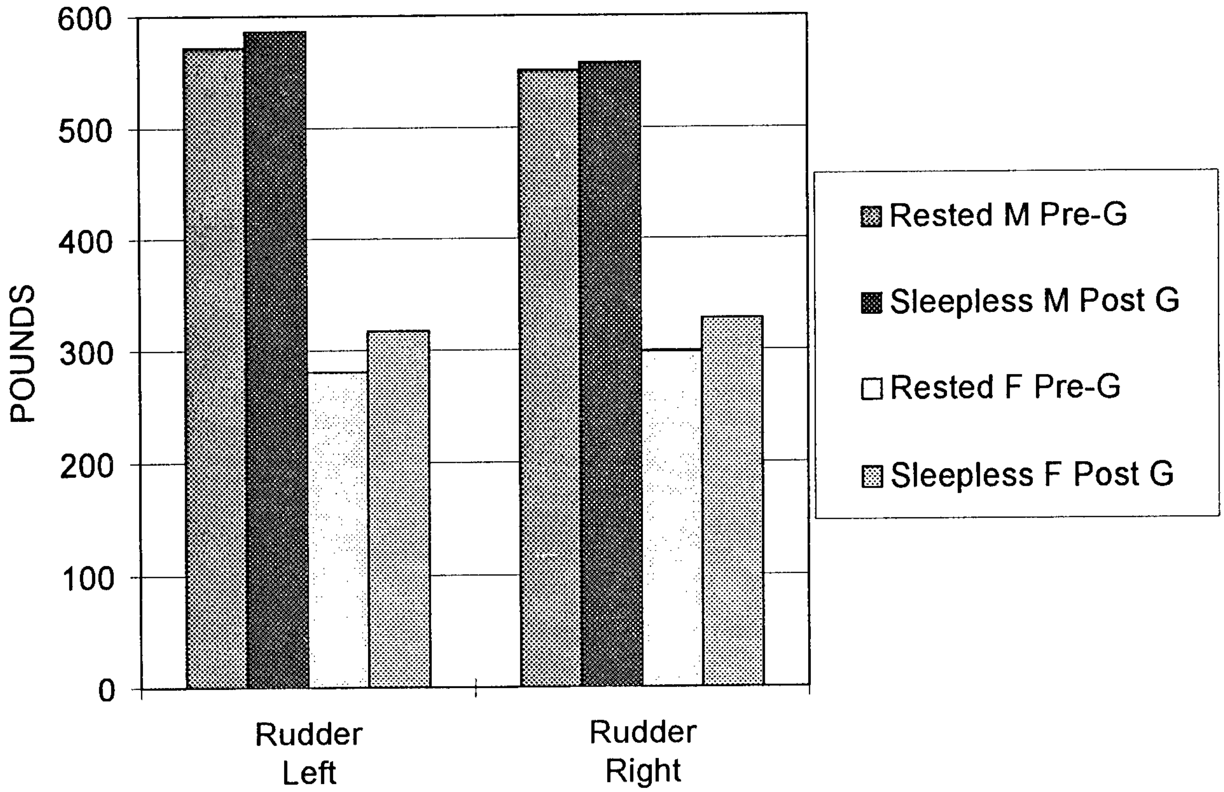

Figure 4. Mean Lower-Body Strength of Men and Women in Both the Pre-G Rested and Post-G Sleepless Conditions.

Figure 5 provides a comparison of upper and lower strength between men and women using yoke back data to represent upper-body strength and average right and left rudder pedal data to represent lower-body strength. These data show that women were 54 percent as strong as men in upper-body strength and 52 percent as strong as men in lower-body strength in the rested condition.

Ejection handle forces generated by the male group were significantly higher than those generated by the female group for the right, left, and both handle conditions $p \leq 0.001$, $p \leq 0.002$, and $p \leq 0.0004$, respectively. Figure 6 illustrates the maximum ejection handle forces generated by each group for each of the three conditions.

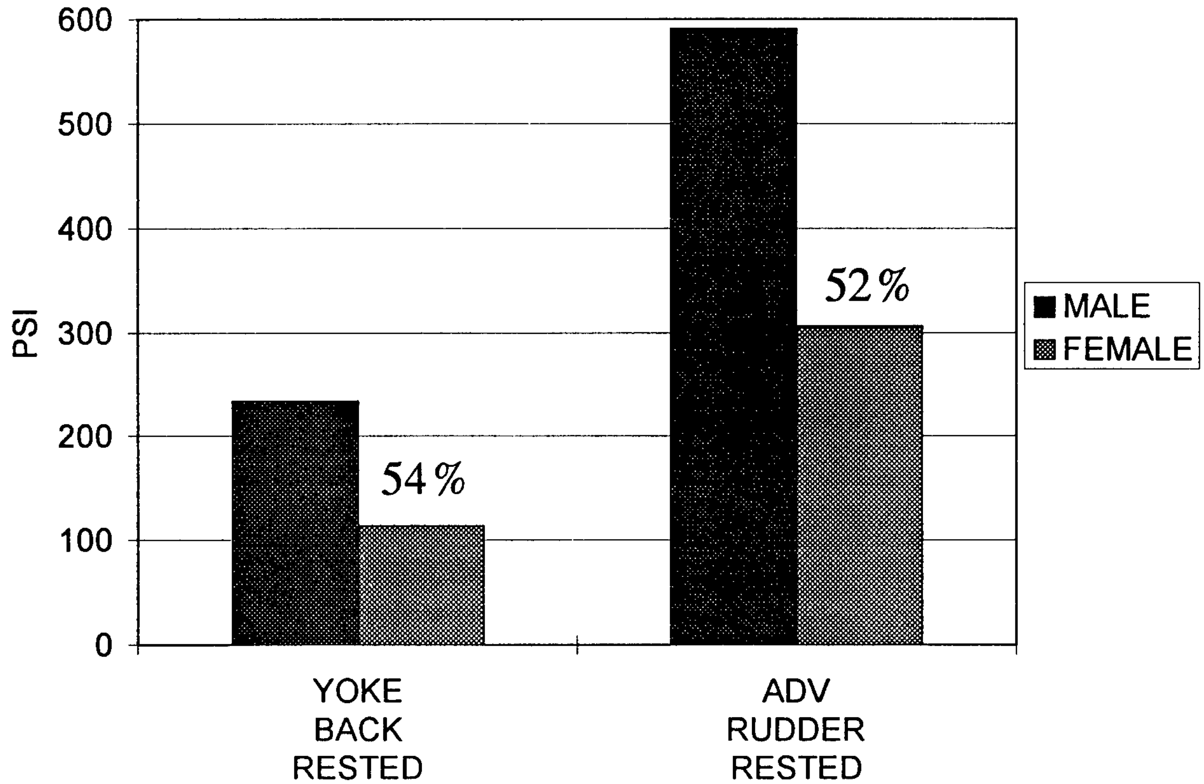

Figure 5. Male and Female Comparison of Upper- and Lower-Body Strength.

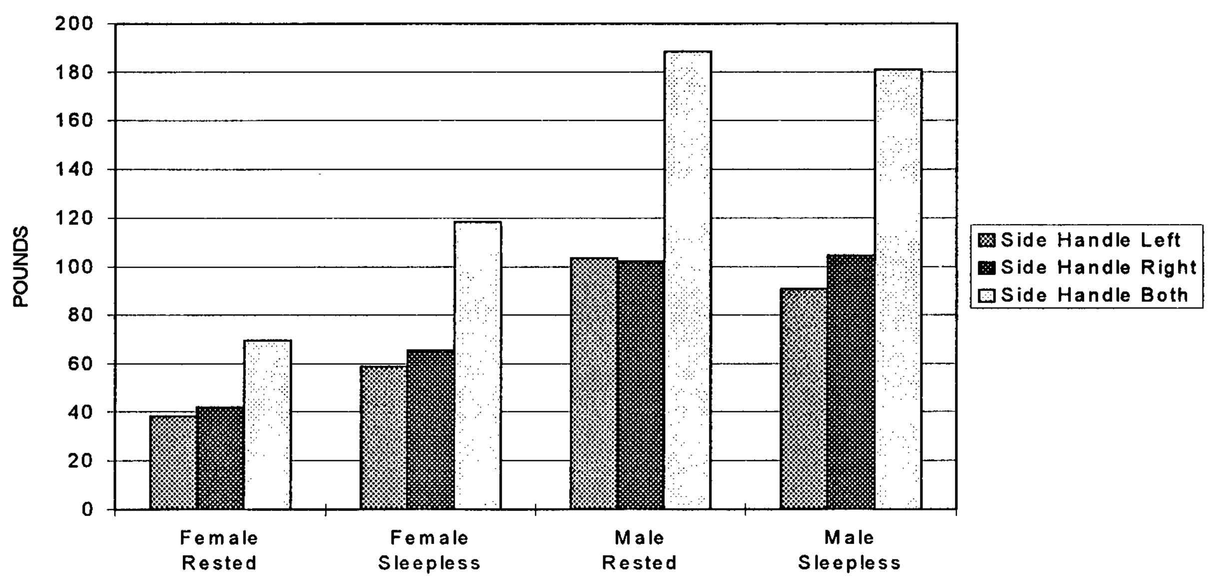

Figure 6. Ejection Handle Strength for Men and Women Comparing the Pre-G Rested to Post-G Sleepless Condition.

DISCUSSION

Historically, strength data have been used almost exclusively to define strength requirements for aircraft designers. McDaniel (6) compared men and women Air Force Academy and Officer Training School candidates who were bound for aviation careers. Results of this work showed a significant difference between men and women and found that arm strength of women did not meet USAF aircraft controls design criteria. About eight years earlier, Leeper et al., evaluated female strength capabilities and how these data were related to the standards set in place by the Federal Aviation Administration for civilian aircraft manufacturers. Results from this work showed that upper-body control force limits for general aviation aircraft were too high for the majority of U.S. female pilots (2). This led to a change in FAA guidelines to aircraft manufacturers. Studies to this point focused mainly on the strength capabilities of men and women needed to operate aileron and rudder pedals. McDaniel and Robbins reported their findings from a study which investigated the amount of force women could generate pulling the ACES II ejection handles (7). The ejection handles were mounted on both the left and right side of the seat as well as center mounted. Results of this study showed a small percentage of subjects could not generate the force required to indicate a successful ejection when pulling the center handle with one hand. McDaniel evaluated this sub-set of the female population and found that the correlation between size and strength was very low. One operational limiting factor of pilots who meet minimum strength requirements is that various types of aircraft require varying degrees of strength to perform flight operations in normal or emergency flight scenarios.

Table 5 is a listing of aircraft and the strength requirements for some Navy aircraft (8). During our study, women exhibited no problems in performing the flight stick inputs in the centrifuge where an F-16 stick was emulated with a maximum input force of 25 lbs.

TABLE 5. Strength Requirements for Aircraft Operation.

Aircraft Type	Flight Operation Condition	Force (LBF)
EA-6B	Freeing stick and auto-throttle	33-55
AV-8B	Free jammed flight controls	35-60
F-18A/B/C/D	Initiate overhead ejection	30-60
S-3B	Emergency flight control system	80/ 4-5 minutes
T-44A	Emergency gear extension	50/ 3-5 minutes
T-45	Canopy closure overhead	50

Adapted from Shender (8)

CONCLUSIONS

Results from this study showed no significant change in strength within groups of men or women when comparing pre-G exposure to post-G exposure in both the rested vs sleepless conditions. Although subjects reported being more fatigued after flying the four high-G air-to-air sorties in the sleepless compared to the rested condition, they still performed as well as they had in the rested condition.

These data may have a far-reaching effect on Air Force Global Reach Policy where aircrew are moved to transatlantic or transpacific locations with minimal sleep and are then required to perform air-to-air combat missions in support of combat operations. These data may also be useful for commanders in the field when making decisions whether to re-launch a pilot who has already been involved in limited air-to-air combat, but who reports subjective fatigue.

REFERENCES

1. Laubach, L.L. Comparative muscular strength of men and women: A review of the literature. Aviat Space Environ Med. 1976; 47:534-42.

2. Leeper, R.C., Hasbrook, H.R., Purswell, J.L. Study of control force limits for female pilots. Oklahoma City: Civil Aeromedical Institute, Technical Report FAA-AM-73 23, DTIC-AD-777 839, Oklahoma City, OK, 1973.

3. McDaniel, J.W. Strength capabilities for operating aircraft controls. SAFE Journal, Fall Quarter, 1994; 25(1):28-34.

4. Dotson, D.A., Krohn, G.S., Thomas, K.E. Accommodation of women in the F-22 cockpit. SAFE. 1994; 25(1):58-63.

5. Chelette, T.L., Albery, W.B., Esken, R.L., Tripp, L.D. Individual performance during high-G simulated flight after 24 hours of sleeplessness. Aviat Space and Environ. Med. 1997. In press

6. McDaniel, J.W. Male and female strength capabilities for operating aircraft controls. AFAMRL Technical Report No. AFAMRL-TR-81-39, DTIC-AD-A098-256, Dayton, OH, 1981.

7. McDaniel, J.W., Robbins, G. The strength for activation of ejection seat controls. Advances in Industrial Ergonomics and Safety IV.1992; 1275-82.

8. Shender, B.S. Female upper body strength requirements in high performance aircraft: A select bibliography. NAWCADWAR-95041-4.6., Naval Air Warfare Center, Warminster, PA, 1995.